REVIEW ARTICLE

A REVIEW ON DROUGHT STRESS IN *SORGHUM BICOLOR:* PHYSIOLOGICAL AND MOLECULAR APPROACH

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Abstract: *Sorghum bicolor* is one of the diverse and staple food crops grown on earth. About 41.97 million hectares on the earth has been cultivated sorghum in the year of 2021-2022. Drought is prevailing problem and important factor all over the world on agriculture production. Along with that, climate change making a serious situation for the cultivation of crops. Sorghum is one of the excellent crops capable of adapting to drastic environmental changes. By understanding the mechanism behind the adaptation and tolerance to the drought, we can make better crop. This review covers the possible approaches in the drought tolerance of the Sorghum such as the morphological character determining the drought stress tolerances, microbial interactions forming symbionts and helping in stress tolerance, breeding and molecular approaches to improve the abiotic stress tolerance and the use of QTLs and Marker Assisted Selection for improving the drought tolerance.

Keywords: Drought stress, Tolerance, Drought genes, Breeding, QTLs

INTRODUCTION

Sorghum (*Sorghum bicolor*) commonly referred as Indian millet, is a cereal plant of the family Poaceae. The origin of the plant is considered to be Africa. It is a drought tolerant C_4 grass plant used for production of grains, forage, sugar, lignocellulosic biomass and a genetic model for C_4 grasses due to its relatively small genome (approximately 800 Mbp), diploid genetics, diverse germplasm and colinearity with other C_4 grass genomes (Mc Cormick*et al.*, 2018). Sorghum is one of the staple food for many peoples of Africa and some parts of Asia. Products such as breads, cakes, porridge and alcoholic drink beer is made out of sorghum grains. Nearly all sorghum production (97%) in western hemisphere is for livestock feed and forage because it is a lower cost alternative to maize and requires less water to grow (Hancock, 2000). The growth stage of the crop and the environmental factors decides the water requirement for sorghum. As imbibitions is the first step of seed germination, water plays a critical role in it. Drought stress is a condition where water loss in plants exceeds the ability of plant roots to absorb water from soil, thereby affecting the plant metabolism and ultimately resulting in yield loss. Plants use three main strategies (drought escape, drought avoidance and drought tolerance) to survive under drought stress (Osmolovskaya*et al.*, 2018). Plants are adapter to tolerance by wide range of responses at physiological, molecular and biochemical levels. Sorghum can tolerate short period of less severe water deficit. However, long term and several stress can affect sorghum growth and the final yield (Assefa *et al.*, 2010). It's tolerance to drought is a consequence of heritable morphological and anatomical characters (such as thick leaf wax and deep root system), physiological responses (such as osmotic adjustment and stay green trait) and adaptive mechanisms that allow tolerance under extreme drought conditions (Tari *et al.*, 2017). This review paper discusses about the drought stress and the physiological and molecular mechanisms in tolerating the drought stress and molecular methods of improving drought tolerance in sorghum.

Sorghum as a dry land crop

Sorghumis an important crop plant in Dry land agriculture. Sorghum's heat and drought tolerance make it well suited to the area's semi-arid summer growing conditions, and its genetic diversity makes the crop potentially useful as a forage, a gluten free grain source, and in biofuel production (Dahlberg *et al.*, 2011). Despite the level of environmental adaption that sorghum display, failure of seedling establishment due to abiotic stress is a major problem (Howarth *et al*., 1996). One strategy for maintaining adequate moisture in the seed and root zone for a longer time period is deeper sowing of the seed, but in this case, growth depends longer on seed reserves before emergence occurs (Howarth *et al*., 1996). Yield instability is another problem when growing grain sorghum in dryland regions. More consistent yields resulted in Australia when every third row or two row of every four rows were left blank compared with uniformly spaced 1-m rows when yields were 2500 kg ha^{-1} or less (Bandura *et al*., 2006). Drought stress affects starch synthesis and energy (ATP) production process through increased respiration

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rate, resulting in reduced index of seedling vigor, GRI and PG (Queiroz *et al.,* 2019). However, the effect of drought stress on different sorghum genotypes may differ due to the variability in their response to the stress. For example, drought stress during terminal post-flowering stage, genotypes with a high growth rate and short duration of grain filling produced larger grains compared to genotypes with longer duration of grain development (Tuinstra*et al.,* 1997). Ngara*et al.,* (2021) reported that Plant response to drought stress and drought tolerance is a result of complex biological processes involving physiological, biochemical, genomic, proteomic and metabolomics changes.

Morphological characters and adaptations of plants in drought stress

Drought tolerance is the ability of a plant to endure the water deficit conditions. Most of the plants at their habitat has one or more adaptations to withstand stress conditions. Crops like sorghum are naturally adapted to dry conditions, while many crops like rice, wheat, maize are designed to adapt to drought conditions by either conventional breeding or through biotechnological approaches. Many structural adaptations like stomatal opening and closing, reduced number of leaf and leaf area, root system changes to increase water absorption, presence of small hairs called trichomes on leaf to absorb water from atmosphere. Plants growing in dry areas have developed xeromorphic traits to reduce transpiration under drought stress (Basu*et al.,* 2016). Assefa (2012), reported that leaf rolling is a good indicator of drought tolerance in plants. Studies of Bibi *et al.,* (2012) reported that root length is an important trait against drought stress in plant varieties. The variety with longer root has the drought resistance ability to absorb nutrients and water availability in soil. Drought tolerance was found to be highly associated with root characteristics such as root thickness, root length density, number of thick roots, root volume and root dry weight (Wagaw, 2019). Many plants have modified leaf like pine needle and avoid drought through sunken stomata. Sorghum and wheat have waxy covering of plant cuticle to control transpiration. This trait was found to be associated with seedling stage of drought tolerance in sorghum.

Symbionts based approach to abiotic stress

Microbial interactions with crop plants are key to the adaptation and survival of both the partners in any abiotic environment. Induced Systemic Tolerance (IST) is the term being used for microbe-mediated induction of abiotic stress responses (Meena *et al*., 2017). Plant growth promoting microbes (Symbionts) are capable of conferring stress tolerance to various host plants and beneficiary to both monocot and dicot crop species. Marasco *et al.,* (2013) reported that microbes isolated from the roots of one host species cultivated under dessert farming conditions are capable of improving the growth of a different host species when grown under water-stress regime. Mayak*et al.,* (2004), found that the bacterium *Achromobacterpiechaudii,* isolated from dry riverbeds of southern Israel, was capable of increasing salt and drought resistance in both pepper and tomato. The Kapoor *et al.,* (2013) stated that Arbuscular Mycorrhizae enhance plant growth productivity and nutrient uptake under stress condition and also enhance osmolyte production, influence plant-water relation and rate of photosynthesis, alter leaf water potential, ionic balance, antioxidant production and other physiological and biological parameters and thus improve plant's capacity to tolerate abiotic stress. The findings of Symanczik*et al*., (2018) suggested that under the drought stress condition, *Rhizophagusarabicus* transfers significantly more Nitrogen to sorghum than *Rhizophagusirregularis*. Recently, bacterial cold-shock proteins transformed into various plant species led to increased tolerance to a variety of abiotic stresses, including cold, heat, and drought (Castiglioni *et al*., 2008).

Breeding and molecular strategies for drought stress

There are three mechanisms through which plants can survive drought tolerance. They are drought avoidance, (fig.1) drought tolerance (fig.2) and drought escape (fig.3). Understanding the genes involved in these mechanism help us to improve the plants to resist the drought and improve productivity. Sorghum is a short day plant, flowering initiation occur in 15th day when plants are exposed to short day light (10 hours) for 5 days (Caddel, 1972). Several salt, drought, and cold-tolerant lines have been developed through breeding and are being maintained in different locations all over the world (Maqbool *et al*., 2001). In general, for self-pollinated crops, pedigree and bulk method can be used and for cross pollinated crops, recurrent selection can be used. Backcross could be used if drought resistant traits are transferring to a high yielding genotype. Biparental mating (half-sib & full sib) maintains the broad genetic base as well as provides the scope to evolve the desired genotype of drought resistance (Yunus*et al.,* 1982).

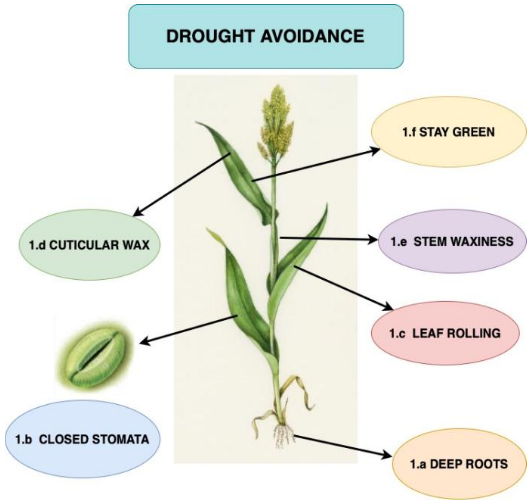

Fig. 1. Drought avoidance mechanisms

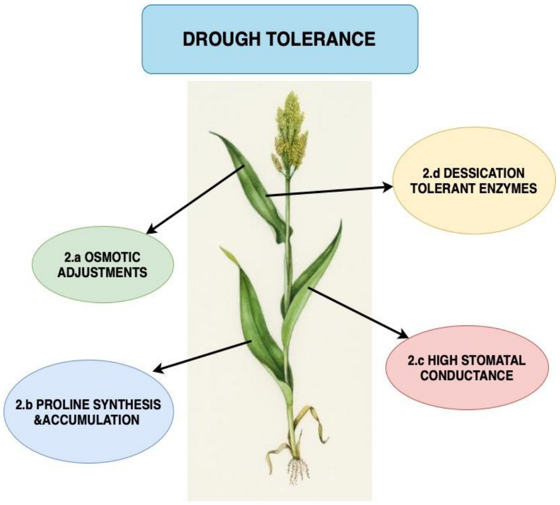

Fig. 2. Drought tolerance mechanisms

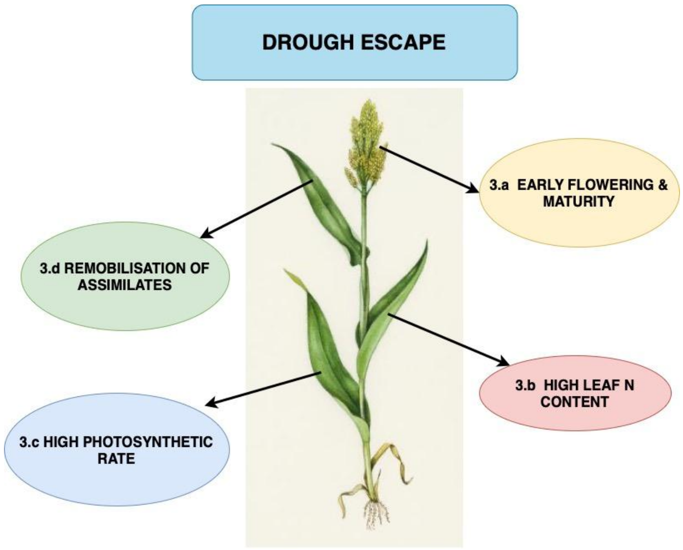

Fig. 3. Mechanisms associated with drought escape.

Identification of the molecular markers associated with yield or other morphological traits related to drought resistance, those markers could be used as selection criteria for drought resistance (Belete, 2018). Molecular markers linked to QTL for drought tolerance could be used in increasing efficiency of breeding efforts to select sorghum germplasm with enhanced drought tolerance once these markers are identified through carefully monitored characterization of appropriate germplasm under stress condition (Belete, 2018). Other techniques include biotechnological approach *ie*., Introducing and expressing the drought tolerant gene to sorghum, which protect sorghum from drought stress. Gene transfer is efficient and time saving method compared to breeding method, which is highly suggestible in recent researches. Proline is an amino acid, which act as osmolytes in plants that protect plant from osmotic stress (Yoshiba*et al*., 1997). *P5CSF129A* gene which synthesis mutated pyrroline 5-carboxylate synthetase, the key enzyme for proline biosynthesis from glutamic acid were transferred to *Sorghum bicolor* through *Agrobacterium tumefaciens* mediated gene transfer and overexpressed. Proline accumulated in transgenic sorghum (Reddy, 2015 & Kishor, 1995). Transferring *mtlD* gene from *E. coli* into *Sorghum bicolor* which encodes for mannitol-1-phosphate dehydrogenase enzyme, as a result the crop can tolerate water deficit conditions (Maheswari*et al*., 2010). Mainly two approaches *ie*., targeted and shotgun approach facilitate genetic engineering to obtain transgenic plants conferring drought resistance (Belete, 2018).

Genes associated with drought tolerance in sorghum

Cuticle is covered by a layer of wax called epicuticular wax. This wax is chemically made up of hydrophobic long chain organic compounds. This plays an chief role in controlling the cuticular transpiration. Many research have shown that drought stress can increase the amount of wax deposition on leaf surface (Yang *et al*., 2011). Bao *et al* (2017) cloned the *Sb*WINL1 gene into Arabidopsis. The results revealed that overexpression of SbWINL1 in Arabidopsis showed increase in wax and cutin. It was also reported that WIN1 gene is responsible for drought and defence responses in plants (Sela *et al*., 2013). Li *et al* (2019) worked on *Sb*ER1 and *Sb*ER2, genes that confer drought tolerance in maize. Their results proved that *Sb*ER2-1 had an important role in drought stress. *Sb*SNAC1 is a plant specific NAC TF. This has a role in governing abiotic stress responses in sorghum. In response to ABA, *Sb*SNAC1 is found to have high expression rate in roots. Findings of Lu *et al* (2013) showed that overexpression of *Sb*SNAC1 gene in transgenic plants showed improved drought stress tolerance. Mittal *et al* (2017) concluded that many drought responsive CDPKs were associated with regulation to confer drought tolerance. Expression of *Sb*WRKY30 gene promises drought tolerance in Arabidopsis. Thus *Sb*WRKY30 may be a candidate gene for drought tolerance (Yang *et al*., 2020).

QTLs and Marker Assisted Selection for drought tolerance breeding

Quantitative Trait Locus (QTL) is the method of locating the genes for quantitative traits with the help of molecular markers. There are many traits identified that govern drought tolerance and are been mapped on sorghum genome. Tunistra*et al*., (1997) studied a set of 98 recombinant inbred sorghum lines for post flowering drought tolerance through QTL. The overview of breeding approach for drought tolerance is given in fig.1. Stay – green in sorghum is one among the very needed trait for drought tolerance. Stay – green trait is the ability of sorghum plant to retain the green leaves even under physiological stress that can enhance the photosynthetic rate. Marker Assisted Selection helps in selection of the parental genotype with the contrasting traits for crop improvement. Molecular markers includes RFLP, RAPD, SSR, AFLP, SNP etc. Among these, Single Nucleotide Polymorphism (SNP) markers can detect the diversity at a single base level (Disasa*et al*., 2016). The SSR markers were found to ease the transfer of important stay-green QTL to sorghum cultivars of interest (Edema and Amoding, 2015). Abou-Elwafa and Shehzad (2018) studied the molecular diversity among 96 sorghum lines with molecular markers. They reported their findings of three drought responsive QTLs ie., Xtxp69 on chromosome 3, *Sb*AGA01 on chromosome 8 and *Sb*AGB03 on chromosome 9. these genes are associated with drought resistant linked phenotypic traits. A collective breeding approaches can be screened and used to develop drought tolerant superior cultivars.

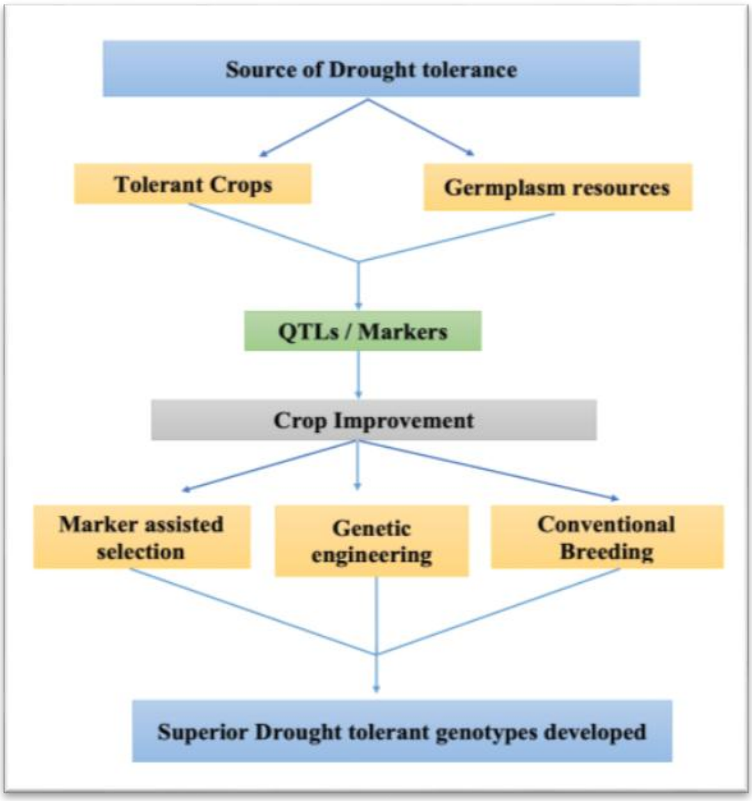

Fig. 1. An overview of collective methods of crop improvement for drought stress

CONCLUSION

Water is one among the basic necessities to maintain life processes. Ultimately irrigation for crops is essential for food security on a global level. Climate changes in the present world contributes majorly for the abiotic stress in plants. Drought stress is normally considered to create a negative impact on plant growth and yield. Generally, plants adopt themself to survive in stress conditions. Severe drought can result in disturbing the photosynthetic rate, leading to altered plant metabolism and thereby resulting in crop failure and yield loss. In the view of crop improvement, understanding the principles of physiological and molecular basis of drought stress is required. Sorghum is naturally referred as camel crop as it is having the high ability of drought tolerance and thus performs well. It is also a C4 plant of good photosynthesis efficiency. Drought stress affects sorghum at every growth stages. So, to gain more understanding of stress effect on plants, detailed molecular study must be done at specific growth stages. Further research should be done on studying the combined abiotic stress components in sorghum for crop improvement. In regard to this, screening for new genotypes with high drought tolerance should be done. Many drought stress governing genes have been mapped and few were also discussed above and molecular mechanisms associated with that are also found. Finally to conclude, the advances that proceed in genetic and molecular studies and modern breeding strategies will enhance sorghum in conferring high degrees of stress tolerance.

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